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Testing Cements with Plastic Mortars.

WE give further abstracts of papers read at the International Association for Testing Materials, held in London recently. Other papers were given in our issue for June last.

By Dr. G. HAEGERMANN.

(BERLIN-KARLSHORST.)

Apart from the existing standard method of testing, the German cements used in road making have, since 1934, been required to be tested by a method which uses a plastic mortar. The new procedure aims at a better conception of the properties of the cement in relation to the actual method of use in practice.

DIMENSIONS OF SPECIMENS.—For practical reasons the specimen should not be too large and for technical reasons it should not be too small. The disadvantage of specimens of large dimensions is that a large amount of material is required while with specimens which are too small inaccurate results may be obtained. The prisms required by the Swiss Standard Specification, measuring 4×4×16 cm., seem to be very suitable, because the bending strength and the compressive strength can be determined on the same specimen.

AMOUNT OF WATER.—Experience has shown that different cements may show very different decreases in strength with increasing water : cement ratios. In testing "moist earth" mortars the extent of the decrease in strength is not realised, hence it is desirable to use a higher water content. In order to avoid loss of water during gauging and moulding the mortar the amount of water used must not be greater than the mass can hold. On the other hand, sufficient water must be used so that the mortar is quite plastic during tamping, that is, during tamping there must be no locking or wedging of the individual particles of the mortar. This requirement will not be fulfilled by coarse sand even if the amount of water lies near the upper limit.

SAND.—The so-called single size standard sand has, on account of its large percentage of voids, the disadvantage that it cannot hold sufficient water.

According to the type of material, the surface properties, and the shape of the grains, a 1 : 3 mixture will hold up to about 12 per cent. water. When German standard sand is used this limit is about 10.5 per cent. This amount of water is not sufficient to fill the voids in such a manner that the mass works during tamping like a truly plastic mortar. The mortar is so harsh that during tamping it behaves exactly like " moist earth " mortar.

Single-size standard sand has also the disadvantage, due to the cement and sand being measured by weight, that the strength is affected by the extent to which the pores are filled by binding material. The " filling effect " is almost completely absent in the case of the aggregate used in practice. It is on account of this that a standard sand of mixed sizes is preferable. The choice of a sand is the most difficult part of the solution of the problem. One would use for this purpose a graded sand containing all sizes from the largest to the smallest. However, in order to prevent segregation during transport this sand must be separated into various sizes before delivery, and the larger the largest particle size the greater must be the number of grades.

For the comparison of cements it is of great importance to know what kind of aggregate will give the highest strength, and it is important that the aggregate will give a sufficient differentiation among the cements according to their true cementing power at the same time avoiding as much as possible the " filling effect " in the pores. Since the quality of the present standard sand has remained constant for many years it should be retained for the largest grade. From a large number of tests it has been found that the addition of only one fine-grained fraction, leaving out the medium grades, will give the same results as a sand containing all grades from the finest to the size of the standard sand. In this way the production of the sand is very much simplified.

For the tests a mixture was used containing two parts by weight of standard sand and one part by weight of fine sand. The fine sand is a true quartz sand obtained as follows. The raw sand is washed and dried and then ground in a tube mill with flint pebbles to the following fineness :

	Per cent.
Residue on a sieve with 0.20 mm. clear aperture	5
Residue on a sieve with 0.088 mm. clear aperture	68
Portion larger than 0.03 mm.	88

Variations in the residue on a sieve with 0.088 mm. clear apertures of $\pm$ 5 per cent. have no effect on the strength or the amount of water required.

METHOD OF CARRYING OUT THE TEST.—First the cement + fine sand (1 : 1) should be intimately mixed, then the standard sand (+ 2) added and the whole mixed dry. After adding 15 per cent. of water the mortar should be treated according to the current German Standard Specification. The amount of gauging water should be determined from the slump. For this purpose a small vibrating table of standard dimensions may be used.* The mortar should be put into a watertight mould (4 × 4 × 16 cm.) in two layers, each layer being

* *Zement*, 1936, p. 98.

tamped. In order that all the prisms may be of the same size the excess mortar should be removed only after two hours. The specimens should be cured as at present. The prisms should be tested for bending strength according to the Swiss Standard Specification. The broken pieces should be tested in compression between steel plates measuring 4 × 6.25 cm.

RESULTS OF EXPERIMENTS.—There must be a basis of comparison with the older method in the strength values obtained by the new method. For well-burned Portland cements the following relationship can be obtained for water-cured specimens.

	Kg. per square centimetre.					
	7 days.			28 days.		
(*a*) Tensile strength	24	28	32	32	35	38
(*b*) Bending tensile strength	40	50	60	52	65	78
(*a*) Compressive strength	300	400	500	400	500	600
(*b*) ,, ,, ...	170	270	370	300	400	500

(*a*) Standard method of testing. (*b*) New method of testing.

According to tests made by Werner-Hedström* and Graf and Schwiete† a much better comparison is given by the new method between the values obtained and the strength of concrete. The results of a questionaire sent to cement works which have used the new method for two years showed that this method was preferable to the old method. It is for these reasons that the new procedure has been introduced as a suggested standard method of testing for Portland cement in Germany.

By PROF. DR. ING. A. GESSNER and ING. A. FRANK.
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An objection raised against the testing of cements using mortars having the consistency of moist earth is that the water-cement-ratio in such mortars is far smaller than that in normal concrete and reinforced concrete. For instance, in Switzerland the strength tests are carried out on prisms made with plastic mortar having a much greater water-cement-ratio. But since the moulding of these prisms is done by hand this method of testing is affected by personal variations. It is suggested that the test specimens should be made from plastic mortar in the same moulds and using the same apparatus as that for testing " moist earth " mortars according to the standard specification.

Fifteen ordinary and twenty high-strength Portland cements were tested according to three methods in a concurrent series of tests :

(*a*) Specimens made from " moist earth " mortar according to the Czecho-slovakian Standard Specification in which the sand and the method of preparation of the specimens conformed to the German Standard Specification.

(*b*) Prisms made from plastic mortar according to the Swiss Standard

* *Engineer*, 1934, p. 235.
† *Protokoll d. Ver. Deuts. Portlandzement Fabr.*, 1916, pp. 30, 71.

Specification of 1932, using German standard sand and a different quantity of water obtained from the formula $\frac{N}{5} + 5$ (N = standard consistency).

(*c*) Standard specimens (tensile strength 8-shape specimens and cubes of 7.1 cm. sides) with the same water content as for test (*b*).

If the specimens are prepared properly according to method (*b*) a constant porosity and density (about 2.20 kg. per dm^3) of the mortar prisms are obtained after hardening. In order to obtain similar conditions for standard specimens made from plastic mortar the work done by the blows in the hammer apparatus must correspond as nearly as possible to the workability of the prisms. From a large number of tests it was found that 30 blows of the hammer gave a density to the prisms of about 2.25 kg. per dm^3 when at the same time water came out between the mould and base plate at the earliest after 20 and at the latest after 30 blows for compression specimens. If this does not happen, a small alteration of the amount of water added according to the formula in method (*b*) will give the consistency required.

The mean strengths of the specimens, which were stored in water the whole time, are given in the table. In the case of the prisms the tensile strength is from the bending tensile strength. If the ratios bending tensile strength : tensile strength and prism compressive strength : standard compressive strength are calculated from the results obtained from methods (*b*) and (*c*) the following values are obtained lower table :

Method of Testing.	Ordinary Portland cements.				High-strength Portland cements.					
	7 days.		28 days.		3 days.		7 days.		28 days.	
	Tension.	Compr.	Tension.	Compr.	Tension.	Compr.	Tension.	Compr.	Tension.	Compr.
(*a*) Standard specimens of "moist earth" mortar	30.7	369	35.7	475	30.7	339	33.0	414	36.5	495
(*b*) Prisms of plastic mortar..	37.7	245	47.4	347	34.9	213	43.3	306	51.8	406
(*c*) Standard specimens of plastic mortar.. ..	25.3	225	31.5	315	24.8	212	28.3	280	33.2	368

The strengths are given in kg. per sq. cm.

	3 days.		7 days.		28 days.	
	Tension.	Compr.	Tension.	Compr.	Tension.	Compr.
Ordinary cements	—	—	1.5	1.1	1.5	1.1
High-strength cements ..	1.4	1.0	1.55	1.1	1.6	1.1

The well-known phenomenon that the bending tensile strength is always higher than the tensile strength of the 8-shaped specimens is immediately recognised. In the usual methods of calculation the latter figure is used for the bending tension. The ratio of bending tensile strength to the true tensile strength rises slowly from 1.4 after 3 days to 1.6 after 28 days for high-strength cements, while for ordinary Portland cements at 7 and 28 days it is practically constant at 1.5.

In the case of the compression specimens it is to be expected that the values for standard cubes with 7 cm. edges would be smaller than those for the broken prisms with 4 cm. sides since the strength rises with decreasing size of the cubes. The ratios for both methods of testing are the same for both high-strength and ordinary Portland cements with one exception.

From these tests it seems that the same valuation of the quality of Portland cements can be obtained with standard specimens made from plastic mortar as with prismatic specimens. Naturally, the values of the standard specimens made from plastic mortar according to method (*c*) will be lower than those made according to the standard method (*a*) which requires a " moist earth " mortar, because a larger amount of water is used. The strengths obtained for specimens made according to methods (*a*) and (*c*) give the following ratios :

	3 days.		7 days.		28 days.	
	Tension.	Compr.	Tension.	Compr.	Tension.	Compr.
Ordinary Portland cements	—	—	1.2	1.6	1.1	1.5
High-strength Portland cements	1.25	1.6	1.2	1.5	1.1	1.35

The ratios for tension and compression decrease as hardening progresses. After 28 days the hardening curves for plastic mortars approach those for " moist earth " mortars. The ratios for compression are always greater than those for tension, hence the reduction of compressive strength due to the greater amount of water is much larger than the reduction of tensile strength.

If Dr. Kühl's coefficients are calculated for the three methods of testing, using the individual values of the strengths of each cement, the ordinary Portland cements fall into three groups in which the weaker cements can be distinguished from those of medium and exceptional quality. It is noteworthy that, in general, the three methods of testing give the same valuation of cement quality. Only one cement from each of the medium and exceptional class go down to the next lower group when tested according to methods (*b*) and (*c*). The high-strength cements fall into two groups, one of which contains those of exceptional quality. In this case also the cements remain in the same group irrespective of the method of testing chosen.

The Design and Operation of Modern Lime Works.—VII.*

By N. V. S. KNIBBS, D.Sc.

GAS-FIRED KILNS

The Theory of Lime Burning by Gas.

THE theory of lime burning by gas is much simpler than that of mixed-feed burning. Complete combustion of the gas furnishes a definite amount of heat which is available for calcination, and there is no difficulty, at least in theory, of ensuring complete combustion. The main problems in gas kiln design are to ensure uniform distribution of the gas (and therefore the heat) over the whole area of the kiln, and to ensure the complete combustion of the gas whilst having a reasonably long zone of combustion without excessive temperature at any point.

The maximum efficiency attainable with any gas composition may be calculated in the way already explained.[1] The gases most used in lime burning are producer gas, natural gas, and mixed blast-furnace and coke-oven gas, and the last named resembles a producer gas because generally only enough coke-oven gas is added to raise the calorific value to that of a good producer gas. The calculation of the theoretical maximum efficiency of a kiln burning typical producer gas and natural gas will therefore nearly cover the field of gas kiln practice. It is proposed here to assume two typical gas compositions and estimate the gas volumes and efficiencies obtainable by their use.

The producer gas chosen has the composition :

Hydrogen	10 per cent.
Carbon monoxide	27 ,,
Methane	3 ,,
Carbon dioxide	6 ,,
Nitrogen	54 ,,
Net calorific value, dry, at 0 deg. C.	150 B.Th.U.s (= 83.3 C.H.U.s)
Weight	7.28 lb. per 100 cub. ft.

This gas theoretically requires 1.12 times its volume of air for its complete combustion, but in practice an excess is always required and under good conditions there may be about 2 per cent. of oxygen in the products of combustion and negligible amounts of unburnt gas. The volume of air used is then 1.37 times that of the producer gas,[2] and the volume of the products of combustion (water not condensed) 2.18,[3] containing 17.8 per cent. carbon dioxide (as measured by gas analysis, water condensed). The weight of the products of combustion

* Previous articles of this series appeared in our issues for January, February, March, April, May and August, 1937.

[1] *Cement and Lime Manufacture*, January, 1937, p. 5.

[2] This volume is given by the formula :

$$V = \left[A + \tfrac{1}{2}H_2 + \tfrac{1}{2}CO + 2CH_4 - (\tfrac{3}{2}H_2 + \tfrac{1}{2}CO + 2CH_4)\frac{A}{100}\right] \div (20.9 - A)$$

where A = % oxygen in products of combustion and H_2, CO, CH_4 = hydrogen, carbon monoxide and methane in the producer gas.

[3] Volume of products of combustion for 1 vol. gas = 1 + vol. air − $(H_2 + CO) \div 200$

is 18.33 lb. per 100 cub. ft. of producer gas (8.42 lb. per 100 cub. ft. of products of combustion), so that the weight per 100 C.H.U.s is $18.33 \div 83.3 = 0.220$ lb. reckoned on the calorific value of the gas, or $18.33 \div 93.6 = 0.196$ lb. reckoned on the total heat in the gas.

In the calculations on producer gas it is assumed that the gas is dry and free from tar and soot. Actually hot producer gas always has some tar and soot and it often contains appreciable quantities of water vapour, but these are variable factors and not easily dealt with in calculations. They influence the results very little and tend to cancel out. The air used in combustion is also taken as dry, and here again the error introduced is small. The volumes given in the calculations are all reduced to N.T.P., and available heats are calculated from 0 deg. C.

Natural gas varies greatly in composition and generally contains some methane, but for simplicity of calculation a gas that is predominantly ethane will be assumed, having the composition :

Methane	94 per cent.
Nitrogen, etc.	6 ,,
Net calorific value, dry, at 0 deg. C.	900 B.Th.U.s (= 500 C.H.U.s)
Weight	4.67 lb. per 100 cub. ft.

This gas theoretically requires nine times its volume of air, and practically, with 2 per cent. excess oxygen, 9.86 times, and the products of combustion measure 10.86 with 10.5 per cent. carbon dioxide. Their weight is 84.3 lb. per 100 cub. ft. natural gas (7.77 lb. per 100 cub. ft. product of combustion), so that the weight per 100 C.H.U.s is $84.3 \div 500 = 0.164$ lb.

In kiln calculations a knowledge of the specific heats of a number of gases over a wide range of temperatures is required, and *Figs.* 25, 26 and 27 have been drawn to supply the required data in convenient form. The curves are based on various measurements mainly as recorded in " The Specific Heat of Gases " by Partington and Shilling. In addition to the curves for the pure gases which occur in producer gas, air, and products of combustion, curves have been drawn for the typical producer gas mentioned and for the products of combustion of that gas and natural gas, each containing 2 per cent. of oxygen. For greater ease of calculation *Fig.* 27 shows the heat capacity of 100 cub. ft. (measured at 0 deg. C. and 760 mm.) of these typical mixed gases. The mean specific heats as shown in *Figs.* 26 and 27 are of most use in calculations, but the true specific heat at definite temperatures are sometimes required and are given in *Figs.* 25 and 27.

Gas generated in a producer adjacent to or built on to a lime kiln will generally enter the kiln at a temperature of 500 deg. C. or more. The total heat introduced into the burning zone by 100 cub. ft. of the typical producer gas at 500 deg. C., assuming its complete combustion, is therefore $100 \times 83.3 + 500 \times 2.065$ (the heat capacity obtained from the curves in *Fig.* 27). The total heat is therefore 9,360 C.H.U.s per 100 cub. ft. (169 B.Th.U.s per cubic foot). To this is to be added the heat introduced by the air, which in turn depends on the quantity of lime leaving the burning zone and the efficiency with which the heat is abstracted from it by the air in the cooling zone.

As previously pointed out[4] the gases leave the burning zone of the kiln at 900 deg. C. They therefore take with them, per 100 cub. ft. of producer gas, $900 \times 2.18 \times 2.19 = 4{,}300$ C.H.U.s (not including the heat in the carbon dioxide liberated by calcination in the burning zone). There is therefore available for actual calcination $9{,}360 - 4{,}300 = 5{,}060$ C.H.U.s, plus the heat in the air entering the burning zone. If the lime enters the cooling zone at 1,100 deg. C. and is cooled to 100 deg. C. in passage without loss by radiation, the heat abstracted

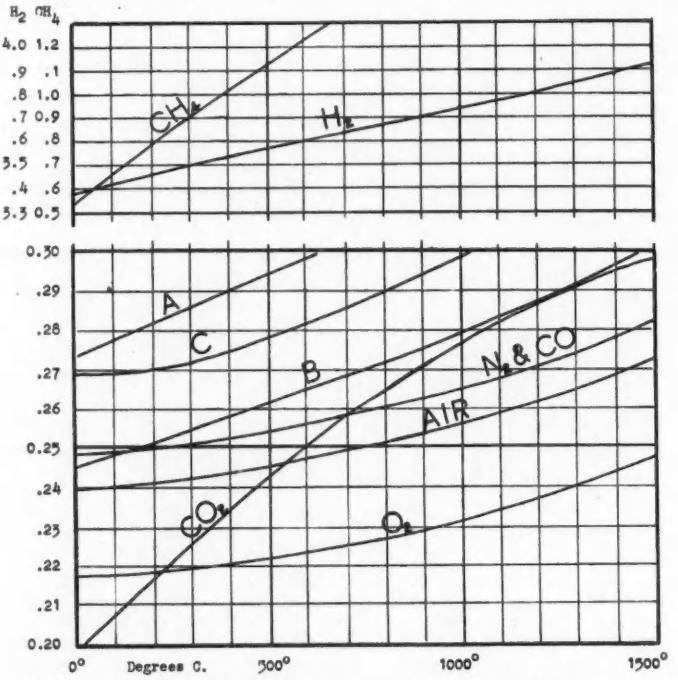

Fig. 25.—True Specific Heats of Gases at Constant Temperature.

A = Producer Gas, $H_2 = 10\%$, $CH_4 = 3\%$, $CO = 27\%$, $CO_2 = 6\%$, $N_2 = 54\%$.
B = Products of Combustion of Producer Gas A with excess Air.
C = Products of Combustion of Natural Gas with excess Air.

from it by the air, per lb. of lime, will be $1{,}100 \times 0.21 - 100 \times 0.19 = 212$ C.H.U.s, so that the total heat in the burning zone available for calcination is $5{,}060 + 212 \times W$. At 900 deg. C. calcination absorbs[5] 694 C.H.U.s per lb. to which must be added the heat required to raise the lime from 900 to 1,100 deg. C., the temperature at which it leaves the burning zone, i.e. $200 \times 0.24 = 48$ C.H.U.s, giving a total of 742.

[4] *Cement and Lime Manufacture*, January, 1937, p. 5.
[5] *Cement and Lime Manufacture*, January, 1937, p. 6.

Theoretically, therefore, the weight W of lime which can be burnt by 100 cub. ft. of producer gas is given by

$$W = \frac{5{,}060 + 212W}{742} \text{ i.e. } 742W = 5{,}060 + 212W, \text{ or } W = 9.5 \text{ lb.}$$

The theoretical maximum efficiency of a kiln burning this gas is therefore $9.5 \times 760 \div 9{,}360 = 77$ per cent. based on the heating value of the gas alone. If producer losses are included the overall efficiency is lower by an amount depending on the producer efficiency. The hot gas efficiency of a producer

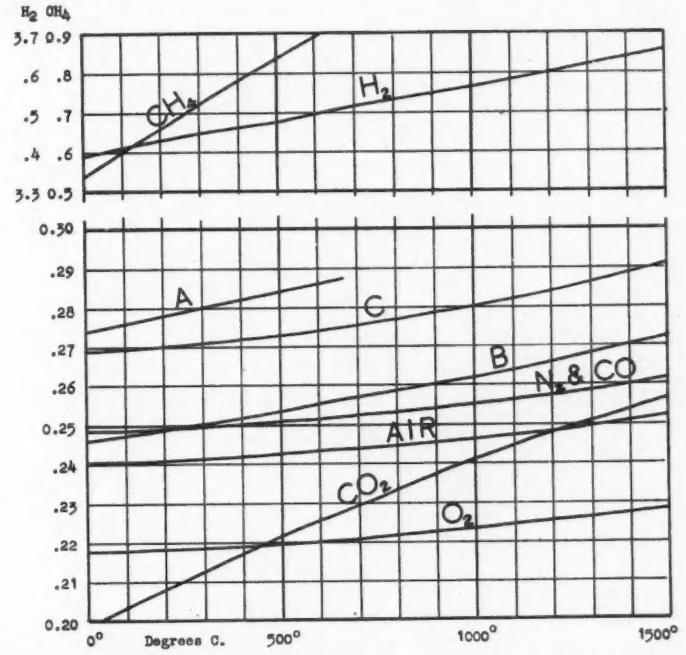

Fig. 26.—Mean Specific Heats of Gases at Constant Pressure between O° and T°C.

A=Producer Gas, H_2=10%, CH_4=3%, CO=27%, CO_2=6%, N_2=54%.
B=Products of Combustion of Producer Gas A with excess Air.
C=Products of Combustion of Natural Gas with Excess Air.

should be at least 90 per cent., and 95 per cent. may be taken as about the maximum actually attained, at which figure the maximum overall efficiency becomes 73 per cent.

The total heat supplied to the burning zone under these optimum conditions would be $9{,}360 + 9.5 \times 212 = 11{,}380$ C.H.U.s, and therefore the temperature reached in combustion, if no heat were lost or taken up by the lime (i.e. the maximum flame temperature) would be about $11{,}380 \div (2.18 \times 2.45)$ (approx.) = 2,130 deg. C. (approx.).

Natural gas supplied cold has only its heat of combustion, which liberates 50,000 C.H.U.s per 100 cub. ft. The heat in the products of combustion leaving the burning zone is $900 \times 10.86 \times 2.16 = 21{,}100$ C.H.U.s, leaving, as heat available for calcination, 28,900 C.H.U.s plus the heat returned from the hot lime, which, on the same assumption as before, will be $212\ W'$, where W' is the weight of lime in lb. burnt per 100 cub. ft. of natural gas. Therefore

$$W' = (28{,}900 + 212W') \div 742, \text{ or } W' = 54.5 \text{ lb.}$$

and the theoretical maximum efficiency is $54.5 \times 760 \div 50{,}000 = 83$ per cent. The total heat supplied to the burning zone would be

$$50{,}000 + 212 \times 54.5 = 61{,}600 \text{ C.H.U.s,}$$

and therefore the temperature reached in combustion without heat loss would be $61{,}600 \div (10.86 \times 2.5)$ (approx.) = 2,270 deg. C. (approx.).

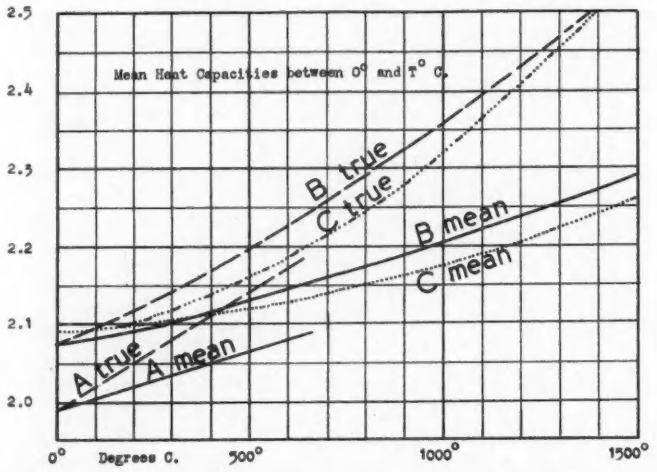

Fig. 27.—Heat Capacities at Constant Pressure of Gases in C.H.Us. per 100 Cubic Feet (the gas volume being measures at N.T.P.).

A = Producer Gas, $H_2 = 10\%$, $CH_4 = 3\%$, $CO = 27\%$, $CO_2 = 6\%$, $N_2 = 54\%$.
B = Products of Combustion of Producer Gas A with excess Air.
C = Products of Combustion of Natural Gas with excess Air.

With complete combustion of the gases, using no more excess air than that assumed, with even distribution over the burning zone and perfect insulation of the burning zone, and with the assumed recovery in the cooling zone, the maximum efficiencies would be attained. Why the efficiency of actual kilns falls short of these figures will be discussed later when dealing with kiln operation.

It might be thought that if the maximum efficiency were attained there would be insufficient heat leaving the burning zone to preheat the stone to 900 deg. C., but this is not so. Take, for example, the natural-gas kiln operating at 83 per cent. efficiency. Per 100 cub. ft. of gas the limestone to be heated amounts to $54.5 \times 1.78 = 97.3$ lb., which requires $97.3 \times 900 \times 0.270 = 23{,}650$ C.H.U.s to

heat it to 900 deg. C. The heat leaving the burning zone in the combustion gases has been shown to be 21,100 C.H.U.s, but to this is to be added the heat in the carbon dioxide evolved in calcination, of which there is $54.5 \times \frac{44}{56} = 42.8$ lb., which therefore contains $42.8 \times 900 \times 0.237 = 9{,}130$ C.H.U.s, giving a total of $21{,}100 + 9{,}130 = 30{,}230$ C.H.U.s; this is an ample margin over the requirements.

The maximum efficiency theoretically attainable when burning natural gas is therefore about 6 per cent. higher than when burning producer gas, or, if the efficiency of the gas producer is taken into account, about 10 per cent. higher. The difference is due to the lower weight of products of combustion of natural gas per unit of heating value, and their consequent lower heat capacity, which entails a lesser proportion of the total heat leaving the burning zone for the preheating zone.

The lower heat capacity also entails a higher flame temperature, as shown, unless heat is abstracted faster than in the producer-gas kiln, and this leads to a consideration of the transference of heat from the flame to the lime. Heat is transferred by radiation from the hot gases to the surface of the lime and by actual contact between gases and lime, and with increase of temperature the amount transmitted by radiation increases rapidly. The radiation of a flame also varies with the kind of gas burnt.

"Surface combustion"—the intense flameless combination of gas and oxygen at a surface which is catalytically active—on the incandescent lime may also be of considerable importance. If it takes place it must result in a high rate of heat transference because the heat is generated actually on the solid surface, but evidence of its occurrence in lime kilns is difficult to secure. The lime-light is doubtless an example of surface combustion, but the pieces of lime in the combustion zone of the kiln are for the most part evolving carbon dioxide, which, flowing out through the surface, would presumably interfere with its catalytic activity in promoting combustion. It is therefore possible that surface combustion takes place only on completely calcined pieces. This may be an explanation of a phenomenon often to be observed in gas-fired kilns: A kiln is burning well and producing good lime, burnt through without being overburnt. Suddenly, through drawing an insufficient quantity, or through missing a draw, the temperature rises, the lime becomes hard burnt, the lumps frit together and it fluxes with the lining, and the whole mass hangs up in the kiln, which often has to be cooled down and the mass broken up with bars before the kiln will function normally again. The very short period that elapses between the time when the kiln is following down normally and producing good lime, and the time when it is hung up and the lime badly overburnt, is a constant source of surprise to gas-kiln operators.

The inference here is that by too long a period between draws, or by drawing too little lime, a wide zone is formed above the gas inlets in which all the lime is fully burnt, and that in this zone surface combustion comes into play, causing

intense activity in limited space and resulting in the evolution of much heat in a zone where there is no endothermic reaction to absorb the heat. Probably a limited amount of surface combustion is an aid to the efficient and complete combustion of the gas and therefore of value to the gas kiln, and with linings of higher refractivity, when burning a pure limestone, it may be possible to operate kilns in future in which the phenomenon is utilised more than at present.

Surface combustion may also furnish a partial explanation of the difference in the ease with which different limestones are calcined. Stones of the same calcium carbonate content and of much the same density and appearance are often reputed to behave very differently in a kiln, and although no exact data are available there seems to be some basis for the belief. Possibly the limes from some stones are more efficient promoters of surface combustion than others, and by analogy one would expect those containing elements having reducible oxides, e.g. iron and titanium, to be the more effective. In the absence of the necessary data, however, this is merely speculation.

Returning to the consideration of heat transference from the flame to the lime it is clear from the data already given[6] on rate of calcination that the burning zone—that is, the zone from the point of maximum temperature upwards to the point where the temperature has dropped to 900 deg. C.—must extend through a considerable height of the kiln, and the higher the average temperature in that zone the shorter it need be. The maximum temperature is limited to that which the lime will withstand without being overburnt. To maintain a temperature close to that maximum, without exceeding it, through a considerable length of the burning zone it is necessary to have a long flame, which may be attained partly by control of the composition of the gas but mainly by ensuring the gradual admixture of the gas and air. It is here that effective design comes into play. By supplying the gas in considerable volume at a few points its admixture with air (and therefore its combustion) is much more gradual than if it is supplied at a large number of points in small quantity. On the other hand, if this is carried too far, complete admixture will be delayed until a zone in the shaft is reached where the temperature is below the ignition point of the gas and incomplete combustion is the result. The composition of the gas—in particular the content of hydrogen—influences the length of flame in the same way as it does in an ordinary furnace, and also, no doubt, the radiation of the flame, but in hot producer gas the soot and other impurities, by supplying incandescent solid particles, probably diminish the effect of gas composition on radiant heat transmission.

Distribution of Gas in a Shaft Kiln.

In ordinary gas-fired furnaces the air, or most of it, is often admitted at a position adjoining the gas inlet, that is to say, mainly as primary air, and in many of the early forms of gas-fired lime kilns the same procedure was adopted. For example, the standard furnace-fired kiln used in the United States was sometimes adapted to gas firing merely by admitting gas (instead of charging coal)

[6] *Cement and Lime Manufacture*, February, 1937, pp. 50 and 51; also April, 1937, p. 125.

to the fire box, where it was burnt, the hot products of combustion passing under the arch into the kiln in the usual way. By so doing nearly all the disadvantages of the furnace-fired kiln were retained ; such kilns were inefficient and costly in upkeep, whilst the maximum diameter that could be used was little more than 6 ft.

The correct method of gas firing a lime kiln is to admit all the air through the lime in the cooling zone of the kiln and the gas through ports opening directly into the shaft. In this way combustion takes place amongst the lime in the zone above the gas port, and the arches of the gas ports remain relatively cool. There is the maximum possible recovery of heat from the lime in the cooling zone and the air is constantly preheated to as high a temperature as possible, and combustion rendered as complete as possible. Furthermore, as in a mixed-feed kiln, the heat is generated in immediate proximity to the limestone absorbing heat, and is therefore used to best advantage. In all modern gas kilns the air, or most of it, is admitted as secondary air through the cooling zone. Some kilns include inlets for admitting primary air but they are seldom, if ever, used.

To attain even calcination in a shaft kiln in which the passage of the stone and lime downwards is uniform, it is obviously necessary for the gases to spread over the whole cross-sectional area of the shaft. The gas must necessarily be admitted through a limited number of openings of limited size, and must spread thence a distance depending on the shaft size. The area over which the gas flame will spread depends on many factors, the important ones being the size and percentage of voids in the lime, the temperature of both gas and air at the burning zone, the positions of the gas and air inlets, the velocity of the gases up the shaft, the volume of gas delivered to the gas port in its relation to the total passing up the kiln, and the velocity of the gas where it enters the kiln.

The size of voids and percentage of void space amongst the lime in the burning zone are the factors which most affect the spread of gas. If the lime is in large pieces of uniform size, and if those pieces are approximately the shape of rough spheres, the spread will be at a maximum, and as already indicated[7] a kiln 9 ft. in diameter may be fairly evenly supplied by four ports in the side wall when it is charged with uniform stone of not less than 6 in. size. In practice it is not practicable to employ such uniform stone, and it does not ordinarily break up to the most suitably shaped lumps. In fact, some limestones are so markedly bedded that they break up into thick plates which tend to pack closely with their least axes across the kiln, thus offering maximum resistance to the spread of the gas. For voids of uniform shape, the spread of the gas is inversely proportional to the size of the stone, and therefore if very large stone is being burnt there would be no difficulty in having kilns of large diameters (accompanied by very great heights) whilst as the size of the stone decreases the allowable kiln diameter is correspondingly reduced.

The spreading of the gas into the air, and vice-versa, depend upon their rates of diffusion and their turbulence, which in turn depend on their temperatures. Consequently hot gas spreads farther than cold gas, and the greater the preheat

[7] *Cement and Lime Manufacture*, February, 1937, p. 59.

of the air in the lime cooling zone the better its admixture with the gas. In general, however, there is little scope for control of these factors, although for other reasons the air should be preheated as much as possible by efficient cooling of the lime. Excess air over that required for combustion (with a small margin) will result in lower air temperature and less efficient admixture and combustion.

The positions of the gas and air inlets and also, in an exhausted kiln, of the exhaust gas off-take, influence considerably the distribution of the gas flame. In some of the earlier kilns the air was admitted at draw doors in the periphery of the kiln[8] and gas through peripheral gas ports. This produced good conditions for gas and the air admixture, but extremely poor conditions of flame distribution across the kiln, and also of air preheat. In a shaft kiln charged uniformly there is least resistance to the passage of gas at the periphery owing to the excess of void space there. Consequently both gas and air tend to move towards the periphery and to pass up the kiln most rapidly at this zone, and the kiln becomes heated most on the walls. As a corollary, the most favourable position to admit gas to a cylindrical kiln is at the centre. From this position, or from a number of positions near the centre, the gas will spread outwards much farther and more uniformly than it will spread inwards from the periphery.

The velocity of the gases up the shaft influences the spread of gas flame inasmuch as a high velocity gives less time for the gas to diffuse outwards in a given length of travel. The capacity of a kiln varies with the velocity of the gases, and therefore a better distribution is obtainable in a kiln operating slowly than when pushed to high capacity. The extent of the spread is not inversely proportional to the velocity, but gases at high velocity are more turbulent so that the spread is inversely proportional to some lower function of the velocity.

The volume of gas delivered at any one point in proportion to the total amount supplied to the kiln influences distribution. This is best realised by thinking of what would happen if the gas were supplied uniformly around the whole of the periphery. There would be so little inward spread that combustion would all take place close to the kiln walls with little inward penetration of flame, By supplying all the gas at one point its penetration is increased to a maximum. but admixture with air may then be delayed so much that combustion is incomplete when the gases have reached a point in the kiln at which the temperature is below the ignition point of the gases, and consequently the exhaust gases contain unburnt gas. It is necessary to balance the advantage of a high volume at one point with the distribution necessary for efficient combustion.

In ordinary furnace work the gas velocity where it enters the furnace is often of great importance in ensuring wide distribution, and it has been contended that the same considerations apply to a lime kiln. It is true that the high velocity of gas through a port of small dimensions is an aid to gas penetration, but it is not of very great importance. The velocity of the gas is reduced to zero in a very short distance, owing to its impinging on the lumps of lime, and thereafter penetratition is uninfluenced by the initial velocity.

[8] As in A, Fig. 13, *Cement and Lime Manufacture*, March, 1937, p. 83.

Effects of Heat Treatment of Portland Cement Clinker.

THE effect of heat treatment of Portland cement clinker on some of the properties of cement is dealt with by Messrs. Wm. Lerch and W. C. Taylor in the Cement Mill Section of *Concrete* for July, 1937. The following is an abstract of their article.

A fundamental objective of research on Portland cement is to attain a method of expressing the composition of cements in terms which may be correlated with their physical properties. Many attempts have been made to correlate the properties of cements with their oxide compositions or their computed compound compositions. These correlations have been useful in the limitation of compositions to meet specified requirements. But the relationships have not been precise and exceptions have occurred which, it is felt, may be due to some other source not evaluated in terms of oxides or computed compounds, but which may be a result of the heat treatment to which the clinker has been subjected during or following clinkering.

A vast amount of valuable information relative to the constitution of Portland cement has been obtained from the application of the principles of Gibbs's phase equilibria supplemented by optical and X-ray methods of identification of the constituents present. It has been found that at clinkering temperatures a considerable amount of liquid is formed. This liquid will contain all or nearly all of the Al_2O_3, Fe_2O_3, and alkalis, together with a large amount of CaO and some SiO_2 and MgO. Some of the reactions leading to the formation of the cement compounds occur by interaction of the liquid with the remaining solid materials and, on cooling from the maximum temperature, the components of the liquid may crystallise as definite compounds or the liquid may partly solidify as a glass.

From the work of Lea and Parker it is possible to calculate the quantity and composition of the liquid formed at the clinkering temperature for any Portland cement composition of the quaternary system $CaO\text{-}Al_2O_3\text{-}Fe_2O_3\text{-}SiO_2$. By the method of calculation proposed by Bogue and Dahl it is possible to calculate the compound composition of the final clinker on the assumption that complete crystalline equilibrium is attained. However, the results obtained indicate that complete crystalline equilibrium is not always attained in the commercial production of Portland cement.

From a study of lime saturation in Portland cements, Forsen, Lea and Parker, Spohn, Solacolu and Kühl have found that the practical limit of lime saturation is often lower than the theoretical limit on the basis of complete crystalline equilibrium. This may be explained on the assumption that for many cements at the clinkering temperature the liquid phase contains less lime than would be required to combine with the alumina to form $3CaO.Al_2O_3$. Then, if the cooling process is too rapid to permit a continuous equilibrium, a " frozen equilibrium " will result in which case there is likely to be some glass present and the ratio of $3CaO.SiO_2/2CaO.SiO_2$ will be higher than that calculated on the basis of complete

crystalline equilibrium. The existence of a frozen equilibrium has been confirmed by microscopic examination of commercial clinkers. Miller also has reported the presence of glass in commercial clinker; he found that the amount of glass varies considerably but states that "there is several per cent. of glass present in even a well-crystallised clinker."

Unfortunately no direct method has been available for measuring the amount of glass that may be present in clinker. Microscopic observations of powder or thin sections have often failed in the identification of appreciable amounts of any isotropic phase, which includes both glass and $3CaO.Al_2O_3$. The differentiation of glass and $3CaO.Al_2O_3$ is further complicated in that both are isotropic and that, within certain ranges of composition, their indices may overlap. The microscopic observations of polished sections of clinker, and a heat of solution method based on the latent heat of crystallisation of the liquid phase, give some promise of more satisfactory differentiation.

Irrespective of a method for determining glass content, and independently of the concept of glass formation, the heat treatment of clinker during or following clinkering may be designed in such manner as to produce clinkers of different structure, and the properties of the cement can be shown to differ with the character of the heat treatment. The present report describes the preparation and behaviour of several groups of clinker compositions which have been subjected to various heat treatments with the object of producing variations in structure or glass content. The nature of the changes which follow in the properties of the resulting cements suggest that some of the irregularities in the observed relationships between the oxide composition or the potential compound composition and behaviour may be explained upon the premise of glass formation, though the glass contents of the clinker used in this investigation have not been determined quantitatively.

Effect on Strength.

Tests indicate that the properties of a cement may vary with the heat treatment even though combination, as indicated by the free lime test, is complete in all cases. Some of these data are shown in Table I. Mixtures *A*, *B* and *C* refer to cements prepared from pure chemicals and *D* from cement rock. The clinkers were ground with 4 per cent. of gypsum to pass the No. 200 sieve and 1-in. cubes of 1 : 3 standard-sand-mortar with uniform water content (12 per cent.) were prepared. It may be noted that there is a general decrease in the strength of each composition at the early ages as the burning temperatures employed exceed that temperature necessary for complete combination. At ages of 3 and 6 months there are only relatively slight differences in the strength values. The specimens prepared from clinker of *A*, burned slowly at 1,410 deg. C., show much lower strengths at the early ages than those prepared from similar clinker burned at the usual rate.

Petrographic examinations of the clinkers of compositions *A* and *B* indicated that crystallisation was more complete in the high-temperature burns. This might be expected, not because of the higher temperatures, but because of the nature

TABLE I.—EFFECT OF BURNING TEMPERATURES ON COMPRESSIVE STRENGTH.
(Strengths recorded represent the average of 3 values which did not differ more than 15 per cent. from the mean.)

Mixture No.	Oxide composition.		Potential compound composition.		Temp. at which liquid disappears.	Temp. of Burning.	Free CaO.	Compressive strength, lb. per sq. in.				
								1 day.	3 days.	7 days.	28 days.	6 m.
		%		%	°C.	°C.	%					
A	CaO	66	C_3S	46	1,340	1,275	4.2	520	810	1,030	1,640	1,960
	SiO_2	23	C_2S	31		1,325	1.2	1,760	2,170	2,910	5,650	6,770
	Al_2O_3	6	C_3A	7		1,375	.3	1,230	2,830	3,640	6,700	6,730
	Fe_2O_3	5	C_4AF	15		1,410	0	2,920	5,330	7,310	7,330	7,330
	MgO	0	MgO	0		1,410 (*a*)	0	660	2,380	2,930	4,940	7,330
						1,450	0	2,420	4,130	4,890	7,630	6,830
						1,500	0	910	2,350	3,380	5,870	7,310
						1,525	0	1,070	2,570	3,350	5,510	7,380
B	CaO	63	C_3S	34	1,300	1,225	10.7	250	300	460	1,040	2,750
	SiO_2	23	C_2S	40		1,275	3.9	520	730	1,020	1,860	4,440
	Al_2O_3	6	C_3A	7		1,325	.6	2,110	2,850	3,440	5,610	8,030
	Fe_2O_3	5	C_4AF	15		1,375	0	1,860	2,850	3,610	6,050	7,620
	MgO	3	MgO	3		1,425	0	1,730	2,280	3,110	5,510	7,560
						1,475	0	1,150	2,140	2,840	5,360	7,440
						1,525	0	1,250	2,180	2,880	4,870	7,040
C	CaO	63.8	C_3S	57	1,300	1,275	5.2	1,540	2,760	3,760	5,100	—
	SiO_2	22.2	C_2S	21		1,325	.6	2,050	2,950	4,370	5,870	7,230
	Al_2O_3	4.0	C_3A	2		1,375	0	2,640	5,250	6,570	6,830	7,430
	Fe_2O_3	5.0	C_4AF	15		1,425	0	2,330	3,890	4,270	6,040	7,120
	MgO	5.0	MgO	5		1,475	0	1,950	3,310	4,230	6,350	7,570
						1,525	0	1,940	3,350	4,310	6,230	7,280
D	CaO	66.4	C_3S	69	1,200	1,375	0	4,070	6,560	7,080	8,190	8,220
	SiO_2	21.5	C_2S	10		1,525	0	3,480	5,450	6,090	7,720	8,050
	Al_2O_3	5.2	C_3A	10								
	Fe_2O_3	2.0	C_4AF	6								
	MgO	4.4	MgO	4.4								

(*a*) This clinker burned at such a rate that it remained in the furnace five times as long as the others.

TABLE II.—EFFECT OF RATE OF COOLING OF CLINKER ON COMPRESSIVE STRENGTH.

Oxide composition.		Potential compound composition.		Cooling Period 1,400° C.–1,275° C. (approx.).	Specific surface.	Compressive Strength. lb. per sq. in., 1-in. cubes; 1–3 mortar.				
						1 day.	3 days.	7 days.	28 days.	3 months.
	%		%		$cm^2/g.$					
CaO	63.2	C_3S	25	2 hours	2,470	50 (*a*)	230	510	900	1,150
MgO	3.0	C_2S	52	20–30 min.	2,570	780	1,540	2,020	3,810	5,070
Al_2O_3	6.0	C_3A	11	5 min.	2,520	1,400	1,800	2,330	3,890	5,640
Fe_2O_3	3.0	C_4AF	9	10 seconds	2,520	1,450	2,050	2,600	6,030	6,660
SiO_2	24.7	MgO	3							

(*a*) Dusted and exhibited flash set.

TABLE III.—VOLUME CHANGE CHARACTERISTICS OF NEAT CEMENT SPECIMENS AUTOCLAVED AT 177 DEG. C.

Comp. No.	Max. burning temp.	Method of cooling.	Oxide analysis of clinker (%).					Potential compound composition (%).					Expansion (%) when autoclaved at 177 deg. C. for (hours).		
			CaO	MgO	Al_2O_3	Fe_2O_3	SiO_2	C_3S	C_2S	C_3A	C_4AF	MgO	24	72	120
1	1,510	With kiln	68.4	0.5	5.7	0	25.5	46	39	15	0	0.5	+0.103	0.221	0.180
	1,510	Cooled slowly to 1,280 deg. C. and held 30 min.											0.103	0.180	0.192
	1,350	With kiln											0.084	0.084	0.084
2	1,500	With kiln	66.4	3.0	5.7	0	24.5	46	36	15	0	3.0	0.231	0.374	0.427
3	1,510	Rapidly	65.2	5.0	5.7	0	24.1	44	36	15	0	5.0	0.327	0.670	
	1,510	With kiln											0.780	1.100	
	1,510	Cooled slowly to 1,280 deg. C. and held 30 min.											(about) 10.000		
	1,350	With kiln											8.800	8.850	
4	1,510	With kiln	66.0	0.5	3.2	4.9	25.5	46	38	0	15	0.5	−0.019	−0.019	−0.006
5	1,510	With kiln	64.0	3.0	3.2	4.9	24.7	44	38	0	15	3.0	+0.075	0.107	0.132
6	1,500	With kiln	62.7	5.0	3.2	4.9	24.2	43	37	0	15	5.0	0.187	0.243	0.280
	1,290	With kiln											5.120	5.200	5.200
7	1,510	Rapidly	65.3	3.0	6.1	2.0	23.1	46	31	13	6	3.0	0.191	0.376	0.412
	1,510	Cooled slowly to 1,280 deg. C. and held 30 min.											2.950	3.010	3.030
	1,200	With kiln											5.130	5.180	5.180

of the horizontal electric furnace in which the clinkers were burned. Temperature measurements made at a point in the cooling zone indicated that, as the temperature of the burning zone was increased, that portion of the cooling zone which was at temperatures conducive to the continuation of crystallisation was lengthened.

A tentative inference from this study was that the decreased strengths of the high-temperature burns (as obtained under the conditions of these tests) may have been due to the more complete crystallisation as indicated by the microscopical examinations. In other words, in this series, the higher early strengths appeared to be associated with higher glass contents. To test the validity of this inference, a series of clinkers from the same raw mixture was burned in this furnace at the same maximum temperature for the same length of time. Four types of clinker were obtained by varying the length of time required to cool from 1,400 deg. C. to 1,275 deg. C. Gypsum was added to give cements having an SO_3 content of 1.8 per cent. The cements were ground to approximately the same specific surface as measured by the Wagner turbidimeter. The results of compression tests are shown in Table II. These results provide further evidence that cooling rates more favourable to glass formation are associated with increased early strengths. Likewise, the beneficial influence on early strength which may be due to increased glass content is again indicated to be apparently less pronounced at later ages.

An attempt was made to produce clinkers of different structure or glass content in an experimental rotary kiln. The clinkers, after being discharged from the kiln, were subjected to various rates of cooling. Examination of the clinkers, however, indicated little difference in the amount or character of crystallisation. Likewise the properties of the cements were little affected by the method of cooling the clinker. Apparently the temperature of the clinker at the point of discharge from the kiln was such that final solidification had already occurred and the temperature of the annealing furnace (1,100 deg. C.) was too low to be effective. This part of the study is now being continued by the preparation of clinkers in a furnace designed especially to permit maximum flexibility in control of the rate of cooling.

Since it had been indicated that some properties of cement may be affected by the heat treatment received by the clinker during burning or cooling, an additional group of cements was prepared of various compositions and burned under conditions more rigidly designed to produce clinkers of different structure or glass content.

Preparation of Clinkers by Different Heat Treatments.

The clinkers designed for study of the effects of various heat treatments were prepared to have potential compound compositions of nearly uniform $3CaO.SiO_2$ and $2CaO.SiO_2$ but of widely varying $3CaO.Al_2O_3$, $4CaO.Al_2O_3.Fe_2O_3$ and MgO contents. (The compositions are given in Table III.) Clinkers were prepared in a gas-fired up-draft furnace by four methods: (*a*) The clinker was cooled rapidly from the maximum temperature by cutting off the gas but leaving the

air valves open so that a current of cold air would sweep through the kiln. Under these conditions it required about 10 minutes to cool the clinker from 1,500 deg. C. to 1,000 deg. C. at which time the air was cut off. (*b*) The gas and air were cut off at the completion of the burning, and the clinker allowed to cool with the kiln. Under these conditions it required about 30 minutes for cooling the clinker from 1,500 deg. C. to 1,000 deg. C. (*c*) The clinkers were heated to about 1,500 deg. C. and then, by proper adjustment of the flame, the temperature was gradually decreased to a temperature just below that of liquid formation. This lower temperature was maintained for about 30 minutes, after which the gas and air were cut off and the clinker was allowed to cool with the kiln. (*d*) The clinkers were prepared at low temperatures, just below that of liquid formation, held at the desired temperature for three hours, and then allowed to cool with the kiln.

The several compositions were not all prepared by each of these four methods. However, the selection of compositions and the thermal treatments to which they were to be subjected were planned so that the results might be expected to indicate: (1) The effect of varying the composition when the method of preparation of the clinker was the same; (2) The effect of varying the thermal treatment of the clinkers of the same composition; and (3) The relative effect of varying composition versus varying thermal treatment. Complete combination was obtained for all clinkers, as determined by the ammonium acetate test for free lime. Gypsum was added to the clinkers in such quantity that the cements would contain 1.8 per cent. of SO_3. The cements were ground to a fineness of 90 to 92 per cent. passing a No. 200 sieve. Three burns of one composition were ground to similar specific surface, about 1,820 square centimetres per gram.

Problems of Clinker Research.

IN *Tonindustrie Zeitung* (1936, p. 607), Dr. H. Kühl gives a brief description of research carried out on the systems of interest in cement research with an explanation of the use of the three-component system CaO-Al_2O_3-SiO_2 in the neighbourhood of the composition of Portland cement. He shows that the problems regarding equilibrium in these systems have been solved. In practice equilibrium is not attained during cooling and the course of crystallisation is more complicated, especially as it is not certain that equilibrium is attained at the highest temperature of the kiln. This latter circumstance makes it difficult to determine what compounds are present at the commencement of cooling.

The work done in the application of the various systems to the manufacture of cement is examined, and a number of methods for determining the maximum allowable amount of lime in a raw mix is discussed. The formula of Lea and Parker for lime saturation ($CaO = 2.8SiO_2 + 1.18Al_2O_3 + 0.65Fe_2O_3$), which was obtained from laboratory experiments, is shown to differ from the author's formula only in the second decimal place. The author's formula was obtained from an examination of the raw mixes used at a large number of cement works and the two formulæ show a very good agreement between theory and practice.

Recent Patents Relating to Cement and Lime.

Admixture for Cement.

458,266. I. G. Farbenindustrie Akt.-Ges., Frankfort-on-Main, Germany. June 15, 1935.

Cement and concrete mixes are rendered more fluid by the addition thereto of a water-soluble salt of an aliphatic or aromatic amine containing at least eight carbon atoms in the molecule. Simple amines, such as dodecylamine chloride, or betaines may be used, e.g. in amount between 0.5 and 2 per cent. by weight of the cement. The betaines prepared from dimethyldodecylamine and sodium chloracetate or β-chlorpropionate may be used.

Colouring Cement.

460,366.—Dewey & Almy, Ltd. (Dewey & Almy Chemical Co.). June 21, 1935.

Such water-soluble organic compounds containing in the molecule at least 15 carbon atoms and two or more aromatic nuclei attached to a heterogeneous nucleus, i.e., a nucleus (which may be a heterocyclic ring) which is characterised by the presence of elements other than carbon and hydrogen, e.g., nitrogen, as will peptise hydraulic cement particles and disperse them uniformly throughout a mix, are added to a concrete mix containing hydraulic cement or to powdered hydraulic cement. The Specification describes tests by which the selection of the compounds may be made. Examples of such compounds are the dyes Fast wool cyanone 3R, Durol black 2B, Durol black B, Wool violet 4BN, Nigrosine 12525 conc., Hypernic extract (Brazilin or the oxidised form brazilein), Fustic extract, Erie scarlet B and Superchrome blue; and phenyl peri-acid and phenyl gamma acid.

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Preventing Efflorescence of Cementitious Materials.

463,406.—Tennant, W. J. (Bakelite Building Products Co., Inc.). Aug. 22, 1935.

The efflorescence of cementitious materials, such as Portland cement and lime and gypsum plasters, in which calcium hydroxide is present or is formed is prevented by incorporating sodium fluoride in the cement before it has set. Other salts which react with the calcium hydroxide to form an insoluble calcium salt may also be added. Additional salts specified are salts of comparatively low solubility, such as magnesium carbonate, magnesium fluoride, aluminium fluoride, and sodium oxalate, and salts of higher solubility, such as ammonium carbonate, sodium carbonate, potassium fluoride, ammonium fluoride, and potassium oxalate; the salts of high solubility are particularly useful when the cement contains a relatively large proportion of free lime. The sodium fluoride, with or without the additional salts, is preferably mixed with the cement during the manufacture of the cement, but it may be dissolved in water and incorporated in the cement just before use. The fluoride is preferably used in such amounts that it will form a saturated solution with the mixing water of the cement and leave an excess of salt, viz., about 5 to 7 per cent. of the cement.

Studies of Mixed Portland Cements.

By SHOICHIRO NAGAI and KIYOSHI INOUE.

THE authors, in continuing the previous studies*, have now reported the results of comparative tests on various kinds of cements, including high siliceous mixed Portland cements which are now being produced on a large scale in some Japanese factories.

Two series of cement samples were tested for chemical compositions, and the results are given in Table 1.

TABLE 1.

No. of Sample	Kind of cement	Loss on ignition (%)	Insoluble residue in 1 : 2–HCl (%)	Total analyses by fusion mixture (%)						Free lime by Emley's test (%)
				SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	
486	Common Portland cement ..	0.34	0.94	22.45	5.90	2.90	65.08	1.63	1.03	—
489	,, ,, ..	0.48	0.14	21.64	6.40	3.49	65.40	0.77	1.06	—
490	Low-heat Portland cement ..	0.94	0.19	24.17	3.58	4.33	64.65	0.87	1.10	—
491	Blastfurnace slag cement ..	–0.11	0.55	26.61	7.36	2.04	55.59	3.18	2.46	—
492	High-silica mixed P.C. ..	0.79	22.74	32.55	6.03	3.44	52.94	1.35	1.40	—
493	,, ,, ..	2.37	18.59	35.78	6.52	2.56	53.25	0.90	0.97	—
494	,, ,, ..	2.44	19.46	36.98	6.63	2.25	49.40	1.08	1.12	—
A	Common Portland cement ..	0.78	0.22	22.68	4.57	3.09	65.07	2.55	1.01	0.72
B	,, ,, ..	1.07	0.44	21.98	4.48	3.50	65.37	1.89	1.07	1.39
C	Low-heat Portland cement ..	0.86	0.36	25.32	3.80	4.10	63.61	0.91	1.02	0.44
D	Blastfurnace slag cement ..	0.12	0.82	27.04	11.79	1.81	53.35	3.45	1.23	0.35
E	High-silica mixed P.C. ..	1.77	—	33.28	7.33	2.97	51.70	1.71	1.22	1.11
F	,, ,, ..	2.55	—	34.72	4.77	2.59	53.30	0.96	0.99	1.18
G	,, ,, ..	2.52	—	38.60	4.41	2.07	50.30	1.07	0.91	1.19

These two series were next compared for some physical properties, fineness, specific gravity, and setting time. The results are shown in Table 2.

The strengths of 1 : 3 non-plastic mortars of these cements were tested, and the results are given in Table 3.

In Table 4 the results are given of tests on specimens made as follows: 1 : 3 cement-sand non-plastic mortars were made in accordance with the Japanese Engineering Standards for Portland Cement and Blastfurnace Slag Cement. Test pieces of 1 : 2 cement and fine sand plastic mortars, modified by the authors from the methods of Professor M. Rös, or Dr. Haegermann, were tested for bending and compressive strengths by prismatic test pieces measuring 4 cm. by 4 cm.

* *Cement and Lime Manufacture*, February, 1936, and June, 1937.

TABLE 2.

No. of sample	Kind of cement	Specific gravity	Fineness (residue) %			Amount of water (%)	Temperature (° C.)	Setting time	
			2500 M/cm²	4900 M/cm²	10000 M/cm²			Initial	Final
								hr. min.	hr. min.
486	Common Portland cement..	3.16	0.9	3.8	—	28.0	31.0	2 24	3 26
489	,, ,, ..	3.17	1.8	4.0	—	27.5	31.0	2 19	3 19
490	Low-heat Portland cement..	3.16	0.7	2.0	—	28.0	29.5	2 35	4 54
491	Blastfurnace slag cement ..	3.01	0.1	1.3	—	29.5	29.0	2 23	4 6
492	High-silica mixed P.C. ..	2.99	0.8	2.4	—	30.5	29.5	1 58	3 21
493	,, ,, ..	2.89	0.4	2.2	—	33.0	28.5	1 35	2 37
494	,, ,, ..	2.79	0.8	1.8	—	32.5	29.0	1 50	2 58
A	Common Portland cement..	3.19	—	3.3	9.4	24.7	20–22	3 4	4 55
B	,, ,, ..	3.17	—	4.5	11.0	24.7	20–22	3 36	5 7
C	Low-heat Portland cement..	3.23	—	3.1	8.8	25.0	20–22	4 15	7 9
D	Blastfurnace slag cement ..	3.02	—	1.2	4.6	27.7	20–22	4 29	6 43
E	High-silica mixed P.C. ..	3.00	—	3.4	7.5	27.9	20–22	3 21	5 14
F	,, ,, ..	2.91	—	1.1	4.6	29.0	20–22	2 9	3 22
G	,, ,, ..	2.82	—	2.9	8.4	30.2	20–22	2 52	4 17

TABLE 3.

No. of sample	Compressive strength (kg/cm²)					Tensile strength (kg/cm²)					Estimation value (C+10T)
	Water (%)	3 days	7 days	28 days	28 days comb.	Water (%)	3 days	7 days	28 days	28 days comb.	
486	28.6	386	490	603	701	25.6	33.6	37.6	43.5	48.7	3814
489	26.8	377	455	574	645	24.8	32.5	34.8	42.7	46.5	3616
490	27.2	239	347	450	550	25.2	27.5	31.2	43.7	52.4	3134
491	29.2	351	505	566	575	26.8	37.0	40.7	51.0	49.8	3782
492	29.4	407	478	532	589	27.6	33.9	34.5	40.4	46.9	3504
493	30.4	467	576	656	747	28.4	34.6	41.0	50.3	55.6	4264
494	30.0	445	578	652	743	28.4	31.6	38.8	50.9	59.6	4227
A	28.5	365	524	647	733	27.3	32.7	36.6	42.2	42.1	3805
B	28.5	382	523	657	713	27.3	33.9	36.2	42.8	36.7	3766
C	28.8	217	329	559	615	27.6	28.6	31.8	40.4	37.4	3102
D	30.5	345	489	640	668	29.3	35.7	40.2	47.6	47.3	3850
E	30.5	393	547	625	663	29.3	34.9	36.3	40.0	39.9	3739
F	31.4	413	611	809	846	30.2	36.3	41.2	51.1	41.1	4376
G	32.0	373	533	742	803	30.8	29.9	36.3	46.1	42.1	3995

by 16 cm. The 1 : 1 cement and fine-sand plastic mortars were also tested for bending and compressive strengths by prisms of the same size, but with different proportions of water, i.e., with the 1 : 2 mortars the water-cement-ratio was 65 per cent. and in the case of 1 : 1 mortars the water-cement-ratio was 45 per cent.

The 1 : 1 : 2 cement and fine standard sand plastic mortars were also moulded with 50 per cent. of water to cement and their bending and compressive strengths were tested by using similar prisms.

TABLE 4.

No. of Sample	Mortar	Water (%)	Compressive strength (kg/cm²)				Bending strength (kg/cm²)				Estimation value (Cw+10B)
			3 days	7 days	28 days	28 days comb.	3 days	7 days	28 days	28 days comb.	
486	1 : 2	65	118	178	284	281	32.2	35.7	63.8	48.9	2667
489	1 : 2	65	91	152	271	272	25.6	38.6	63.0	56.9	2627
490	1 : 2	65	40	64	162	167	17.3	21.5	41.8	38.0	1619
491	1 : 2	65	130	225	315	331	37.9	49.4	65.2	69.9	3225
492	1 : 2	65	125	157	206	248	34.2	45.7	54.7	53.2	2614
493	1 : 2	65	129	167	306	336	35.7	42.4	68.7	59.8	3004
494	1 : 2	65	109	165	303	289	28.4	41.5	67.0	62.0	2855
A	1 : 1 : 2	50	161	254	421	464	29.3	32.9	52.4	59.6	3042
B	1 : 1 : 2	50	165	220	403	463	24.1	28.3	51.2	55.5	2842
C	1 : 1 : 2	50	87	132	295	379	17.0	24.8	37.2	47.5	2158
D	1 : 1 : 2	50	146	269	483	538	28.3	37.4	52.8	58.2	3208
E	1 : 1 : 2	50	210	295	399	438	30.6	38.6	43.0	50.5	2969
F	1 : 1 : 2	50	206	336	552	608	29.4	36.3	52.6	68.0	3565
G	1 : 1 : 2	50	165	256	491	606	24.3	33.4	50.3	55.2	3150
486	1 : 1	45	242	241	594	560	55.9	88.0	115.0	70.8	5114
489	1 : 1	45	238	400	550	560	53.5	86.2	120.0	85.7	5203
490	1 : 1	45	106	181	470	381	29.5	44.4	89.2	60.2	3371
491	1 : 1	45	234	371	555	558	54.5	69.3	90.4	78.7	4647
492	1 : 1	45	265	363	405	440	61.9	72.2	75.9	70.1	4274
493	1 : 1	45	258	382	570	621	50.2	71.1	73.9	74.8	4531
494	1 : 1	45	228	337	556	563	48.1	64.5	79.7	80.1	4405

From Table 4 it is seen that special low-heat Portland cements (No. 490 and C) had the lowest strengths at early ages (3 and 7 days), and that the high-silica mixed Portland cements (Nos. 492 to 494 and E to G) were high-grade cements having the highest strengths at early ages.

The authors are now studying mixed Portland cements in connection with resistance to sea water and aggressive salt solutions, heat of hydration, expansion and contraction, etc.

Trade Notice.

DUST REMOVAL.—Messrs. Davidson & Co., Ltd., of Sirocco Engineering Works, Belfast, have issued a useful folder illustrating and describing their well-known "Sirocco" centrifugal and reversible propeller fans and "Aeroto" screw fans for ventilation and dust removal. This Company has been responsible for dust removal installations in many cement factories, in which class of work it has specialised for many years.